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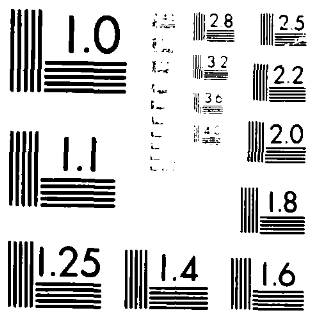

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FPL 414

Nondestructive Evaluation of Mechanical Properties of a Structural Flakeboard Made from Forest Residues

Abstract

A total of 151 full- size structural flakeboard panels constructed from forest logging residue and subpanels and small specimens cut from some of these panels were subjected to several nondestructive tests including two different types of stress waves. Small specimens from 65 of the panels were tested to destruction to determine the different types of strength properties of the structural panels. Some of the nondestructive properties were highly correlated with each other, particularly when measured on the same specimen; others were somewhat less well correlated. Correlations between destructive and nondestructive properties tended to be only moderately good when the nondestructive property was measured on the destructive specimen, and poorer if measured on a larger piece from which the destructive specimen was cut. Results should be of interest to particleboard material scientists with particular interest in nondestructive testing and to standards writing committees.

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Nondestructive Evaluation of Mechanical Properties of a Structural Flakeboard Made from Forest Residues

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Background and Introduction

A good nondestructive test method will enhance the quality and use of particleboard as an engineering structural material. Burmeister (3)[2] and later Pellerin and Morschauser (6) demonstrated in limited ways that nondestructive stress-wave tests could aid in predicting strength properties of particleboard. Based on the Pellerin-Morschauser research, stress-wave equipment has been introduced in a few particleboard plants to maintain quality control. Further gains will be made in the acceptance of stress-wave testing and other testing methods for particleboards as their relationships to strength become better known.

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]*Italicized numbers in parentheses refer to literature cited at the end of this report.*

Further study of the problem came about when the Forest Service set out to demonstrate that forest residues could be used to make a good quality structural flakeboard suitable for house roof and floor sheathing. To evaluate the flakeboard made from forest residue, 151 four- by eight-foot panels were made on a commercial-type 4- by 20-foot single opening press. Sixty-five of these were used for making the small ASTM standard tests (*1, 2*), while others were used in assemblies for wall racking and fire testing (*5*).

In addition to the ASTM standard strength tests, tests with compressional stress waves, ultrasonic or impact (*4*), were conducted on full panels and on subpanels and small specimens cut from the full panels. Each full panel was also subjected to a sag bending test. This report describes and examines results of several nondestructive tests of particleboard, emphasizing correlations among the nondestructive and the standard destructive tests.

Panel Processing

The 151 full-size 4- by 8-foot panels were stored at 73° F and 50 percent relative humidity (RH) for moisture conditioning. Full-panel testing then began with measurement of physical dimensions, weight, panel sag under own weight, and transit time for impact and ultrasonic stress waves on all 151 panels. Thirty-one of the panels not designated for small-specimen tests were cut into pairs of 4- by 4-foot half panels. Except for the sag test the above measurements also were made on these half panels.

Each of the 65 full panels designated for small-specimen tests was cut as shown in figure 1. Each panel was first crosscut into four equal 2- by 4-foot quarter panels. Except for the sag test, the large panel-type measurements then were made on each quarter panel. The four quarter panels from each of the 65 full-size panels were then designated at random for a concentrated load puncture test, standard small-specimen tests, an impact test, and moisture properties (evaluated in another study).

Quarter panels designated for the standard small-specimen tests were cut into twelfths, three equal 16- by 24-inch twelfth panels. The full panel-type measurements were than made on all these, except the sag test. The three twelfth panels cut from each standard small-specimen quarter panel were then randomly assigned to one of the following standard strength property groups: static bending, rail, and interlaminar shear; nail, ball impact, and hardness; plate shear.

The twelfth panels were cut into the standard small specimens. All of these standard small specimens and all the quarter panels designated for puncture and impact tests were stored at 73° F, 65 percent RH for conditioning prior to strength testing. Dimensions, weights, and stress-wave times as well as the destructive specimen properties were then measured on the small specimens and the puncture and impact quarter panels.

An outline summarizing the various nondestructive measurements made on each type of specimen is shown in table 1.

Nondestructive Testing Procedures

Weight and dimensions of each panel, subpanel, and small specimen were measured. Thickness was measured to 0.001 inch with a dial gage having 3/8-inch-diameter contacting surfaces to insure bridging gaps between panel surface flakes. For full, half, quarter, and twelfth panels and plate shear specimens, the thickness was measured at four panel points—about 2 inches in from each edge near the center of each side. Length

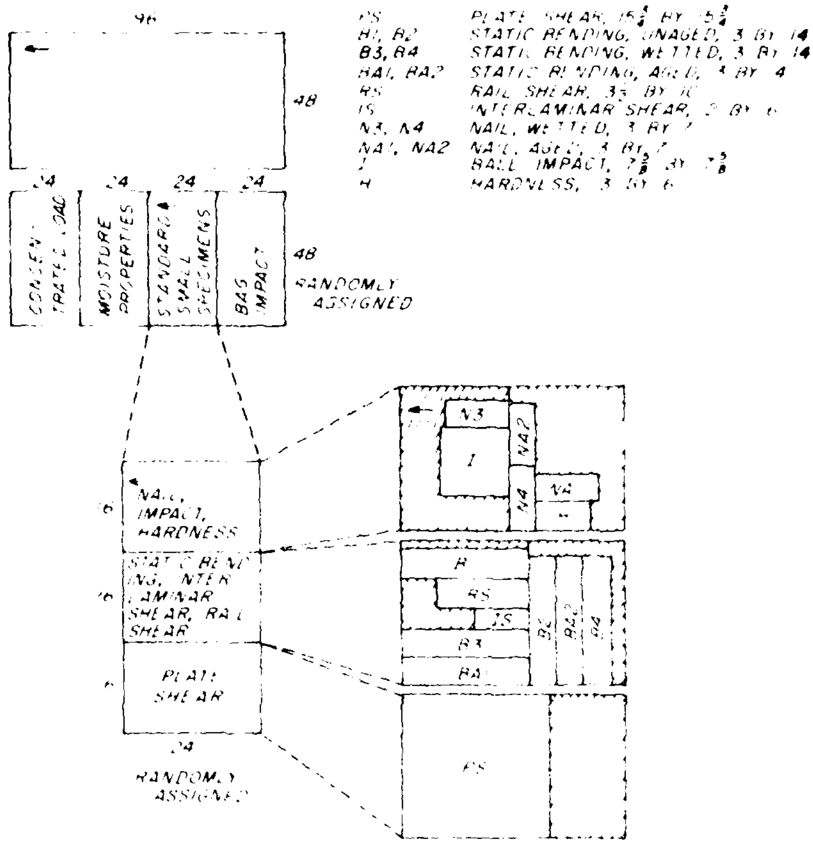

Figure 1.—Diagram for cutting subpanel and small specimens from the full panels. All dimensions are in inches. Arrows indicate panel orientation.

Table 1.—Summary of nondestructive measurements

Specimen type	Weight	Length	Width	Thkns.	Stress-wave time: Ultrasonic, Along panel	Ultrasonic, Across panel	Impact, Along panel	Impact, Across panel	Sag
Full panel	X	X	X	X	X	X	X	X	X
Half panel	X	X	X	X	X	X	X	X	
Quarter panel	X	X	X	X	X	X	X	X	
Twelfth panel	X	X	X	X	X	X	X	X	
Panel shear 15-3/4 by 15-3/4	X	X	X	X	X	X	X	X	
Static bending 3 by 14	X	X	X	X	(1)	(2)	(1)	(2)	
Rail shear 3-1/2 by 10	X	X	X	X	X				
Nail 3 by 7	X	X	X	X	(1)	(2)			
Ball impact 7-5/8 by 7-5/8	X	X	X	X	X	X			
Hardness 3 by 6	X	X	X	X	X				
Interlaminar shear 2 by 6	X	X	X	X	X				

[1]Long axis of the specimen coincident with the along panel direction.

[2]Long axis of the specimen coincident with the across panel direction.

and width were measured along the panel centerlines. For the 14- inch-long bending and 10- inch-long rail shear specimens, thickness was taken as the average of thickness measurements at the center and at about 2 inches in from each end. For the remaining small-specimen types, thickness was measured only at the specimen center.

For treated bending and nail specimens (water-soaked or aged), weights and dimensions used here are based on before treatment data.

Full-panel sag measurements (fig. 2) were based on supports spaced 95 inches apart. The yoke with the dial gage attached was zeroed in the vertical orientation shown in figure 2 on the milled surface of a new testing machine. While perfect zeroing could not be assured, zeroing was felt to be sufficiently close to allow three significant digit accuracy in the panel sag test (all panels were expected to sag more than 1 in.). Panel sag was measured as shown and also with the panel inverted to account for any inherent panel warpage. Taken as the average of these two measurements, sag was only determined for the full-size panel in the orientation shown; sag tests would be less accurate on smaller spans.

Compressional stress-wave transit times were always measured along a centerline. For the impact waves, the panel or smaller specimen was placed in a clamp attached to a solenoid-operated impactor. An accelerometer was mounted on that clamp to signal the microsecond timer to start when an impact was induced (see later discussion on timing bias under Results – Bias in Impact *t*). Another accelerometer was clamped 1 inch in from the panel or specimen edge opposite the impactor to signal the timer to stop as the stress wave reached that point. The transit time for any one test was taken as the average time for three successive impact measurements. The impact timing test setup with a half panel is shown in figure 3.

For the ultrasonic tests, a 40-kilohertz transducer and matched

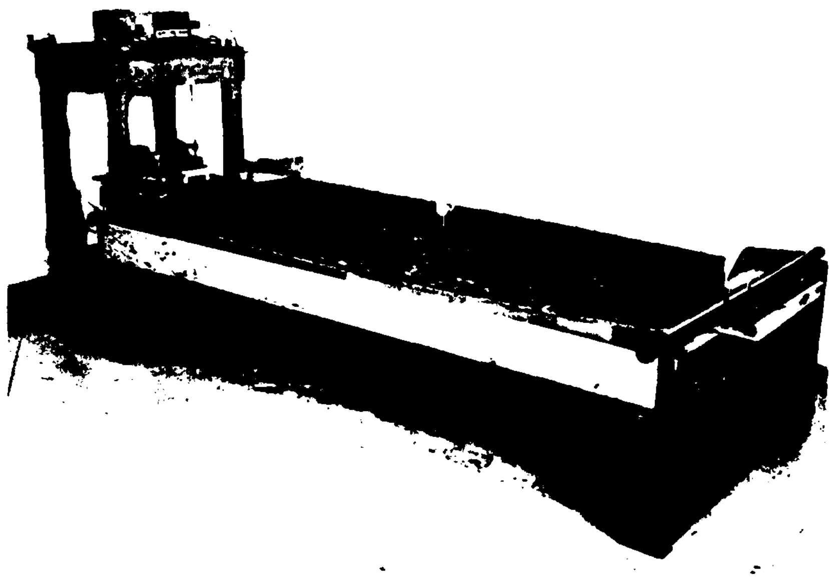

Figure 2.—Full-panel sag test setup. Bar supports and deflection yoke are on a 95-inch span. Impact and ultrasonic stress-wave devices are shown to the left of the panel.

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Figure 3.—Impact stress-wave test setup with a 48- by 48-inch half panel. The solenoid-operated impactor is clamped to the far side of the half panel while the "stop" accelerometer is clamped to the near side. Timing instrumentation is contained in the larger box on the table. The ultrasonic timer and transducers are to the right of the impact timing meter.

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receiver were held to the opposite edges of a panel, subpanel, or small specimen. Pulses from an ultrasonic timer activated the transmitter at about 0.1-second intervals and the timer sensed the receiver transducer to determine stress-wave transit time. The ultrasonic timer and transducers are shown to the right of the impact timing meter in figure 3.

Nondestructive Property Calculations

Unit stress-wave time (τ), either ultrasonic or impact, was calculated from

$$\tau = t/\ell \qquad (1)$$

where τ is in microseconds per inch (μs/in.) when ℓ is the stress wave transit distance in inches and t is the transit time in μs. In practice, ℓ was the panel or specimen dimension in the timing direction when the ultrasonic device was used and 1 inch less than that when the impact device was used.

For comparison of the smaller subpanels with those cut from the larger subpanels, or panels, unit stress-wave times for the smaller subpanels were determined by

$$\tau = (\Sigma t)/(\Sigma \ell) \qquad (2)$$

when the transit distance of the smaller pieces was a subdivision of the larger piece (e.g., the along-panel direction in the half panels for comparison with the along-panel direction in the full panel, or the across-panel direction in the twelfth panels for comparison with the across-panel direction in the quarter panel) or by

$$\bar{\tau} = [\Sigma (t/\ell)]/n \qquad (3)$$

when the transit distance was the same (e.g., the across-panel direction in half panels with $n = 2$ for comparison with the across-panel direction of the full panel).

Modulus of elasticity (E) based on stress-wave data was calculated according to the fundamental equation

$$E = \rho c^2$$

where ρ is density and c is stress-wave speed. The actual equation used was

$$E_{SW} = 1.4977\, D\, (1/\tau)^2 \qquad (4)$$

which yields E in 10^6 pounds per square inch (lb/in.^{2}) when density (D) is in pounds per cubic foot (lb/ft^3 including moisture content), and τ is in μs/in.

Modulus of elasticity from the sag test was based on the assumption that the panel was uniformly loaded over its full length, with the uniform load based on the panel's density. The actual equation used was

$$E_{SAG} = 8.627\,(10^{-11})\, DL^4/(T^2\delta) \qquad (5)$$

which yields E in 10^6 lb/in.^{2} where D is as given above, L is panel length in inches, T is panel thickness in inches, and δ is the deformation of the panel center in inches due to sag when spanning 95 inches between supports (fig. 2).

Equation (5) does not account for shear deformation. Presumably, shear deformation would be relatively small because of the large span-to-depth ratio.

Where applicable, stiffness was calculated as the imposed load in pounds divided by the resultant deformation in inches, with stiffness having the units lb/in. as for a spring. Stiffness so calculated could serve as a nondestructive property if all panels were of uniform and equal thickness. Otherwise, a form of E which reflects thickness variation would be more appropriate. For the concentrated load tests on the quarter panels, however, E would be difficult to calculate as the relative flexural stiffness in along-panel and across-panel directions, modulus of rigidity, and Poisson's ratios must be known (7). Consequently, as flexural E is inversely related to the cube of thickness, a unit stiffness (US) was calculated for the quarter-panel concentrated load tests from

$$US = 300/(T^3\delta) \qquad (6)$$

where US has the units lb/in.^{4} with T as above and δ, the deformation in inches, measured relative to the subpanel supports due to the 300-pound load.

The thickness used in equations (5) and (6) and for all density calculations was the average value of the four thickness measurements per panel, subpanel, or plate shear specimen or the single value for each smaller specimen.

For density comparisons of smaller subpanels with the larger subpanel or panel from which each was cut, density for the smaller subpanels was calculated as the sum of subpanel weights divided by the sum of subpanel volumes.

Results

Because this study is directed toward evaluating properties measured nondestructively and potentially useful for predicting strength properties, the main emphasis will be on how well destructive and nondestructive properties relate. These relationships will be discussed in terms of correlation coefficients, that is, how well a destructive property correlates with a nondestructive property in a simple regression analysis. The simple linear regression model appeared to be adequate, based on data plots.

Panel thickness and density are included in this report as they are important properties associated with the nondestructive and destructive tests. For reader convenience, the subpanel and small specimen regression data are summarized in the appendix. Other mechanical property data may be found in reference 5.

Thickness

The thickness measurements on the 15 small-specimen types cut from each of the 65 triplet twelfth panels were subjected to an analysis of variance to demonstrate within and between panel variation. Thickness averaged 0.509 inch over all 975 specimens. The estimated variance for thickness was 0.0001575 (standard deviation of 0.013 in.) between panels and 0.000077 (standard deviation of 0.008 in.) within panels. Thickness ranged between 0.47 and 0.54 inch for panel averages and 0.46 and 0.56 inch for individual specimens. As will be seen later, the variation in thickness had a significant effect on the correlations between destructive and nondestructive tests.

Density

As with thickness, the density data (weight and volume at 65 percent RH) on the 15 small specimens per panel were subjected to an analysis of variance. Density averaged 45.3 lb/ft³ over all 975 specimens. The estimated variance for density was 4.44 (standard deviation of 2.1 lb/ft³ between panels and 4.64 (standard deviation of 2.2 lb/ft³) within panels. Density ranged from 41.1 to 51.3 lb/ft³ for panel averages and from 36.6 to 56.4 lb/ft³ for individual specimens.

Unit Stress-Wave Time (τ)

As shown in table 2, τ averaged about 8.6 μs/in. along the full panel and 9.5 μs/in. across the full panel by the ultrasonic method and slightly higher by the impact method. Because ultrasonic τ decreased somewhat with a decrease in timing distance (table 2 and fig. 4), and because there seems to be some bias in impact τ as discussed below, an analysis of variance of τ was limited to ultrasonic τ and to smaller specimens of about equal length.

For the along-panel direction, ultrasonic τ data on nail (2 specimens per panel), ball impact, hardness, and interlaminar shear specimens, all 6 to 7-1/2 inches long,

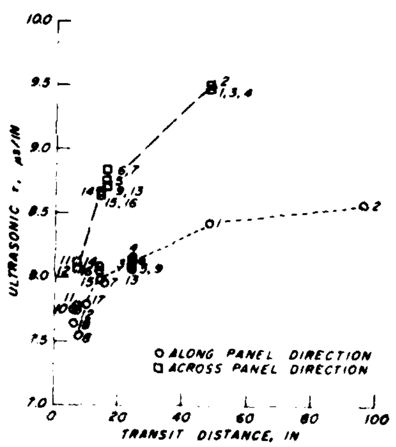

Figure 4.—Unit ultrasonic time (τ) as a function of measuring distance. Numbers correspond to reference numbers in table 2 and identify the specimen type.

Table 2.—Average results for unit stress-wave time (τ)[1]

Specimen type	Number of replications	Along panel Ultrasonic μs/in.	Along panel Impact μs/in.	Across panel Ultrasonic μs/in.	Across panel Impact μs/in.	Ref. No.[2]
Full panel	151	8.60	8.80	9.51	9.78	
Full panel	31	8.62	8.87	9.52	9.88	
Half panels[3]	31	8.42	8.79	9.48	9.88	1
Full panel	65	8.57	8.80	9.50	9.80	2
Quarter panels[4]	65	8.12	8.80	9.47	9.85	3
Quarter panel	65	8.15	8.80	9.48	9.86	4
Twelfth panels	65	8.09	8.74	8.74	9.71	5
Twelfth panel	65	8.13	8.77	8.83	9.80	6
Plate shear	65	7.95	8.74	8.83	9.76	7
Twelfth panel	63	8.08				
Ball impact	63	7.55				8
Twelfth panel	65	8.08		8.70		9
Hardness	65	7.74				10
Nail, along panel, wet	65	7.78				11
Nail, across panel, wet	65			8.11		11
Nail, along panel, aged	65	7.73				12
Nail, across panel, aged	65			8.06		12
Twelfth panel	65	8.07	8.72	8.70	9.66	13
Bending, along panel	65	8.08	8.92			14
Bending, across panel	65			8.66	9.63	14
Bending, along panel, wet	65	7.97	8.81			15
Bending, across panel, wet	65			8.63	9.75	15
Bending, along panel, aged	65	8.04	8.87			16
Bending, across panel, aged	65			8.63	9.69	16
Rail shear	65	7.78				17
Interlaminar shear	64	7.64				18

[1]Based on properties before any treatment of bending or nail specimens.

[2]Numbers used to identify data in figure 4

[3]Data represent both half panels per full panel

[4]Data represent all four quarter panels per full panel

[5]Data represent all three twelfth panels per single quarter panel per full panel.

were subjected to an analysis of variance to indicate within and between panel variance. Ultrasonic τ averaged 7.68μs/in. for the 325 specimens. The estimated variance was 0.04168 (standard deviation of 0.20 μs/in.) between panels and 0.07241 (standard deviation of 0.27 μs/in.) within panels. For those small specimens, ultrasonic τ ranged from 7.2 to 8.4 μs/in. for panel averages and from 6.2 to 8.7 μs/in. for individual specimens.

For the across-panel direction, the analysis of variance was made on the across-panel ultrasonic data for the three twelfth panels, three bending specimens, and the plate shear specimen, all having a transit distance of 14 to 16 inches. Ultrasonic τ averaged 8.71 μs/in. for those 455 specimens. The estimated variance was 0.09134 (standard deviation of 0.30 μs/in.) between panels and 0.06380 (standard deviation of 0.25 μs/in.) within panels. For those specimens, ultrasonic τ ranged from 8.2 to 9.4 μs/in. for panel averages and from 7.7 to 10.3 μs/in. for individual data.

Bias in Impact τ's. — Impact τ's apparently lacked the variation with transit distance demonstrated by ultrasonic τ's (table 2), but this may have been a result of testing technique. The impact stress wave was actually timed from a point within the steel gripping clamp rather than at the edge of the specimen as was done with the ultrasonic stress wave. Thus, each impact stress-wave measurement should have a more or less constant positive time bias. Differences between ultrasonic τ and impact τ averages (table 2) can be accounted for by a random 3- to 10-μs timing bias for the impact method. Because of the timing bias, the analysis presented from here on was based on the ultrasonic measurements, except for some correlations that immediately follow.

Correlations Between Timing Types and Panel Directions Within Specimens.—Based on measurements made within the same specimen, and for the same panel direction, the two types of τ's (ultrasonic versus impact) were relatively well correlated in quarter-sized panels or larger (table 3, $R \geq 0.90$), but were only moderately well correlated in the smaller sized plate shear specimen (R as low as 0.76).

On the other hand, alike τ's (table 3) in the along- versus across-panel directions were relatively poorly correlated (R ranging between 0.26 and 0.65), implying that the across-panel properties may not be very predictable from the along-panel properties in the type of flakeboard used in this study.

Correlations Between Small Specimens, Panels, and Subpanels.—The correlation coefficients shown in table 4 suggest relatively good relations for ultrasonic τ between full panels, quarter panels, and twelfth panels ($R \geq 0.81$). The correlation coefficients for ultrasonic τ between the small specimens and the subpanels or panels from which they were cut tended to be poor to moderate (R's ranging from 0.23 to 0.77); the better correlation coefficients tended to be associated with the longer specimens (plate shear, rail shear, and bending) and the poorer with the shorter specimens (hardness, nail, and interlaminar shear). Correlations of small specimens with quarter panels or twelfth panels were approximately the same, but were poorer with the large panels. Correlation coefficients generally tended to be better for the across-panel direction than for the along-panel direction.

Table 3.—Correlation coefficients between types of unit stress-wave time data[1]

Type	Full panel	Half panel	Quarter panel	Twelfth panel	Plate shear
Along panel					
Ultrasonic versus impact	0.93	0.97	0.90	0.90	0.76
Across panel					
Ultrasonic versus impact	.91	.96	.98	.84	.84
Ultrasonic					
Along versus across	.50	—	.52	.65	.26
Impact					
Along versus across	.47	—	.34	.50	.30

[1]Each number based on 65 paired values, half-size panel numbers based on 31 paired values.

Table 4.—Correlation coefficients between specimen types for unit ultrasonic time[1] [2]

Specimen type	Full panel		Quarter panel		Twelfth panel	
	Along panel	Across panel	Along panel	Across panel	Along panel	Across panel
Quarter panel	0.92	0.93				
Twelfth panel	.81		0.88	0.94		
Plate shear	.60	.61	.59	.68	0.77	0.67
Ball impact	.61		.52		.70	
Hardness	.36		.51		.47	
Nail, wet	.23		.32		.48	
Nail, wet		.43		.54		.58
Nail, aged	.32		.37		.45	
Nail, aged		.47		.61		.65
Bending	.48		.55		.58	
Bending		.60		.67		.62
Bending, wet	.62		.73		.69	
Bending, wet		.64		.77		.77
Bending, aged	.48		.57		.60	
Bending, aged		.69		.72		.65
Rail shear	.60		.69		.73	
Interlaminar shear	.54		.46		.55	

[1]Each number based on 65 paired values; ball impact numbers based on 63 paired values and interlaminar shear numbers on 64.

[2]Data taken prior to any wetting or aging of nail and bending specimens

Modulus of Elasticity

Calculated from unit ultrasonic stress-wave time and density data, ultrasonic modulus of elasticity (E) in 10^6 lb/in.^{2} averaged between 0.92 (full panel) and 1.18 (interlaminar shear specimen) for the along-panel direction and between 0.75 (full panel) and 1.06 (nail specimen before aging) for the across-panel direction (table 5). Averages in table 5 show an increasing trend in E with a decrease in specimen stress-wave timing distance for both along panel and across-panel directions. That trend, however, is consistent with the decreasing trend of unit ultrasonic time noted earlier.

An analysis of variance was made for ultrasonic E but was limited similarly to that for ultrasonic τ. For the 325 ball impact, hardness, interlaminar shear, and nail (2 per panel) specimens, all 6 to 7-1/2 inches long, ultrasonic E along the panel direction averaged 1.16(10^6) lb/in.^{2} Estimated variance was 0.00924 (standard deviation of 0.10(10^6) lb/in.^{2}) between panels and 0.01115 (standard deviation of 0.11(10^6) lb/in.^{2}) within panels. The along-panel ultrasonic E of those small specimens ranged from 0.89 to 1.41(10^6)lb/in.^{2} for panel averages and from 0.77 to 1.80(10^6) lb/in.^{2} for individual specimens.

Analysis of variance for the across-panel direction was made on the three twelfth panels, three bending specimens, and the plate shear specimens, all based on across-panel lengths of 14 to 16 inches. For those 455 specimens, the across-panel ultrasonic E averaged 0.90(10^6) lb/in.^{2}. The estimated variance was 0.00686 (standard deviation of 0.08(10^6) lb/in.^{2}) between panels and 0.00448 (standard deviation of 0.07(10^6) lb/in.^{2}) within panels. The across-panel ultrasonic E ranged from 0.74 to 1.07(10^6) lb/in.^{2} for panel averages and 0.61 to 1.29(10^6) lb/in.^{2} for individual data.

Correlations Between Panel Directions Within Specimens.—Correlation coefficients relating along-panel to across-panel ultrasonic E's for 65 data sets each were 0.49 for full panels, 0.64 for quarter panels, 0.70 for twelfth panels, and 0.68 for plate shear specimens. These are generally better than the similar correlations for ultrasonic τ (table 3.) Even so, these moderate correlations suggest that across-panel properties will not be predicted very closely by along-panel ultrasonic E.

Correlations Between Small Specimens, Panels, and Subpanels.—Ultrasonic E correlations between small specimens and the twelfth panel from which they were cut (table 6) were moderate to good (R = 0.56 to 0.87). These correlations were all better than the same comparisons for ultrasonic τ (table 4), indicating an improvement due to accounting for density differences, but also thickness because the density calculation involved thickness. On the other hand, ultrasonic E correlations between small specimens and the full panels were poor to moderate (R = 0.22 to 0.57) and were generally lower than the comparable correlations for ultrasonic τ.

Comparison of Ultrasonic and Sag E.— Sag E, as measured on all 151 full panels, averaged 0.88(10^6) lb/in.^{2}, or about 96 percent of the average full-panel ultrasonic E in the along-panel direction. Sag E reflects along-panel stress-strain response. The coefficient of variation was 8.3 percent, a value somewhat higher than the 5.7 percent observed for the comparable ultrasonic E. The larger variation in the sag E is probably due in part to the variable panel thickness noted earlier. Sag E depends on thickness cubed; ultrasonic E depends on thickness to the first power.

The correlation coefficient between sag E and ultrasonic E along the full panel was a moderately poor 0.41. The comparative data are shown in figure 5. Correlations of small-specimen or subpanel ultrasonic E's with the full-panel E from the sag test (table 6) were generally poor to insignificant (R's between 0.03 to 0.45).

Comparison of Static E of Small Bending Specimens with Ultrasonic E.—Moduli of elasticity (table 7) determined from static-bending tests of small specimens depended on panel orientation similar to that noted earlier for ultrasonic E, namely that the along-panel direction had the greater static E. The static E's averaged considerably lower than the ultrasonic E's for the same specimens, however. For the unaged specimens, static E's averaged 71 and 76 percent of the ultrasonic E's in along-panel and

Table 5.—Average of results for ultrasonic modulus of elasticity[1]

Specimen type	Number of specimens	Along panel	Across panel
		----10^6 Lb/in.^{2}---	
Full panel	151	0.92	0.75
Full panel	65	.93	.76
Twelfth panel	65	1.02	.86
Plate shear	65	1.06	.86
Twelfth panel	63	1.05	
Ball impact	63	1.20	
Twelfth panel	65	1.05	.90
Hardness	65	1.13	
Nail, along panel, wet	65	1.13	
Nail, across panel, wet	65		1.03
Nail, along panel, aged	65	1.14	
Nail, across panel, aged	65		1.06
Twelfth panel	65	1.04	.90
Bending, along panel	65	1.03	
Bending, across panel	65		.91
Bending, along panel, wet	65	1.08	
Bending, across panel, wet	65		.92
Bending, along panel, aged	65	1.05	
Bending, across panel, aged	65		.92
Rail shear	65	1.14	
Interlaminar shear	65	1.18	

[1]Before any wetting or aging.

Table 6.—Correlation coefficients between specimen types for modulus of elasticity[1]

Type of specimen	Full panel Ultrasonic E		Sag E	Twelfth panel Ultrasonic E	
	Along panel	Across panel		Along panel	Across panel
Quarter panels[2]	0.65	0.74	0.28	0.81	0.90
Twelfth panel[2]	.58	.61	.32	—	—
Plate shear	.54	.57	.19	.87	.80
Ball impact	.53	—	.15	.78	—
Hardness	.36	—	.22	.56	—
Nail, wet	.38	—	.09	.66	—
Nail, wet		.27	.17		.68
Nail, aged	.45		.18	.65	
Nail, aged		.22	.21		.69
Bending	.39		.21	.70	
Bending		.49	.06		.70
Bending, wet	.45		.30	.79	
Bending, wet		.54	.04		.81
Bending, aged	.38		.19	.71	
Bending, aged		.51	.03		.74
Rail shear	.51		.45	.85	
Interlaminar shear	.38		.29	.76	

[1]Each number based on 65 paired values; ball impact numbers based on 63 paired values and interlaminar shear numbers on 64.
[2]Based on one subpanel per panel.

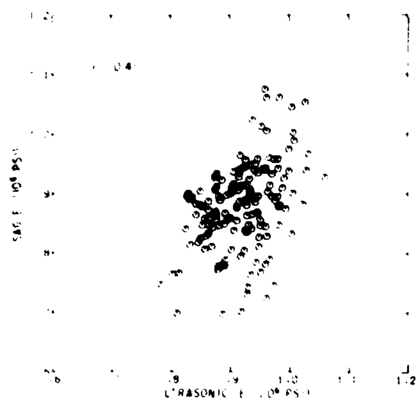

Figure 5.—Comparison of along-panel moduli of elasticity data from sag and ultrasonic measurements—151 full panels.

across-panel directions, respectively. The still lower static E's for the wetted or aged bending specimens reflect a reduction due to treatment. Note that ultrasonic E's were based on before treatment time, weight, and dimension measurements and static E's on before treatment dimensions but on load-deflection diagrams after treatment. Had static E's been based on after treatment dimensions, the average values for treated specimens would have been lower than those listed in table 7 due to thickness swelling.

Static E's had higher coefficients of variation than ultrasonic E's of the same specimens. The coefficients of variation for static E (table 7) ranged between 13 and 19 percent compared to 11 to 12 percent for ultrasonic E of the same bending specimens. As noted for sag E above, static E is also dependent on thickness cubed which may explain why it was more variable than ultrasonic E.

Correlations between static E and ultrasonic E for the small bending specimens (table 7) were moderately good (R's ranging from 0.70 to 0.85 depending on treatment type). Correlations of small bending-specimen static E's were generally not as good with twelfth-panel or full-panel ultrasonic E's as with the small bending-specimen ultrasonic E's.

Evaluation of Concentrated Load Tests on Quarter Panels

As shown in table 8, concentrated load test results on the quarter panels correlated only moderately well with quarter-panel ultrasonic E (R's from 0.54 to 0.74) but only poorly at best with full-panel ultrasonic E (R's from 0.03 to 0.47). While a correlation coefficient above about 0.25 is significant in a statistical sense (5 pct level, $n \approx 60$), the correlation coefficient should be on the order of about 0.5 or greater if a nondestructive test (NDT) property is to be given serious consideration as a predictor of strength. Correlations of the concentrated load results with the full-panel sag E, not tabulated, were even worse in that none of the R's was significant.

Unit stiffness was moderately well correlated with ultrasonic E of the quarter panel ($R = 0.72$ or 0.74), an improvement over stiffness that was uncorrected for panel thickness. Maximum load in the puncture test, however, was less well correlated with the quarter-panel ultrasonic E ($R = 0.61$), nor was it improved much with a thickness correction ($R = 0.64$).

Evaluation of Static-Bending Properties

Correlation coefficients between maximum load or modulus of rupture (based on before treatment dimensions) from the small static-bending tests and nondestructive specimen or panel properties are given in table 9. Correlations were slightly better for modulus of rupture than for maximum load, as modulus of rupture is corrected for thickness. In general, the destructive properties were best correlated with small-specimen static-bending E (R's from 0.62 to 0.89). Correlations tended to be better with ultrasonic E than with either ultrasonic τ or density. Also, correlations tended to be better with the smaller sized specimen properties than with the larger sized panel properties of the same NDT kind. An example of the decreasing trend in correlation is shown in figure 6 for modulus of rupture of untreated specimens versus ultrasonic E. The results for the across-panel direction in untreated bending specimens are an exception in that the correlations

Table 7.—Summary of small-specimen static-bending modulus of elasticity results and comparisons with ultrasonic modulus of elasticity[1]

Bending-specimen type	Static-bending E: Average	Static-bending E: Coefficient of variation	Correlation coefficient—static E versus ultrasonic E of: Bending specimen, Along panel	Bending specimen, Across panel	Twelfth panel, Along panel	Twelfth panel, Across panel	Full panel, Along panel	Full panel, Across panel
	10^6 Lb/in.^{2}	Pct						
Unaged, along panel	0.73	16.7	0.80		0.69		0.46	
Unaged, across panel	.69	16.5		0.73		0.63		0.55
Wet, along panel[2]	.55	19 1	.70		.76		.52	
Wet, across panel[2]	.49	18.9		.78		.64		56
Aged, along panel[2]	.68	12.8	.85		.57		.27	
Aged, across panel[2]	.61	14.8		.83		.68		.42

[1]Each number based on 65 paired values.

[2]Based on dimensions before treatment.

Table 8.—Results for concentrated load tests on quarter panels

Concentrated load test	Correlation coefficient with along-panel Ultrasonic E	
	Quarter panel	Full panel
Stiffness (3-in. diam.)	0.54	0.03
Unit stiffness (3-in. diam.)	.72	.30
Stiffness (1-in. diam.)	.57	.06
Unit stiffness (1-in. diam.)	.74	.32
Puncture load	.61	.42
Puncture load/thickness	.64	.47

tended to be better with twelfth-panel ultrasonic E's than with the bending-specimen ultrasonic E's.

The small-specimen destructive properties correlated poorly at best with the full-panel NDT properties (R's from 0.03 to - 0.49). This is particularly evident in correlations with density and sag E.

Correlations for the wet or aged bending specimens were very similar to those for the unaged bending specimens.

Evaluation of Internal Bond

Correlation coefficients between internal bond (from untreated static-bending specimens) and non-destructive properties are given in table 10. Except for sag E, better correlations were obtained between internal bond measured on specimens cut from along-panel static-bending specimens and the along-panel NDT properties than between internal bond measured on specimens cut from the across-panel static-bending specimens and the across-panel NDT properties. For all practical purposes, however, almost all of the correlation coefficients were poor or insignificant.

The negative correlations listed for the across-panel direction do not make sense, as they imply that internal bond decreases as ultrasonic E increases. However, only the −0.25 correlation coefficient is significant (5 pct level) in the statistical sense. Even so, such supposedly significant results can be expected to occasionally occur by chance alone.

Evaluation of Interlaminar Shear Properties

Correlation coefficients between interlaminar shear and NDT properties are given in table 11. Shear strength was best correlated with small-specimen shear modulus (R = 0.8) and next best with either ultrasonic E of the twelfth panel or density of either the shear specimen or twelfth panel (R = 0.6). Shear stiffness and shear modulus were best correlated with small-specimen density and twelfth-panel density or ultrasonic E (R = 0.7). Correlations of shear properties with the full-panel properties were mediocre to insignificant, particularly for density and sag E.

Evaluation of Rail Shear Properties

Correlation coefficients between rail shear and NDT properties are given in table 12. Correlations were slightly better for shear stress than for shear load. The shear properties were moderately well correlated with ultrasonic E or density of the shear specimens (R about 0.6) and with the twelfth-panel ultrasonic E (R about 0.54). Correlations with sag E and density of the full panels were insignificant.

Evaluation of Nail Properties

Correlation coefficients between nail-resistance properties and NDT properties are given in table 13. Nail-resistance properties were generally best correlated with nail-specimen density (R's from 0.37 to 0.70), or with twelfth-panel density (R's from 0.29 to 0.70), but the few correlations run with full-panel density were not significant.

In general, correlations of nail resistance with ultrasonic E of the nail or twelfth panel were rather mediocre, but somewhat better than the poor-to-insignificant correlations with ultrasonic τ of the same specimen types. Correlations of nail-resistance properties with full-panel NDT properties were poor to insignificant, particularly for sag E

Evaluation of Ball Impact Properties

Correlation coefficients between the height of drop to first crack or to failure in the ball impact test and NDT properties are given in table 14. The correlation coefficients for failure were only moderately good at best (R about/0.60/), with about the same result for ultrasonic τ as for ultrasonic E: the correlations were generally improved by correcting for specimen thickness. Correlation of failure under impact with full-panel sag E was insignificant and all of the correlation coefficients for first crack under impact were insignificant. Also, there was very little correlation between the first crack and failure (R = 0.47).

Evaluation of Hardness Modulus

Correlation coefficients between hardness modulus and NDT properties are given in table 15. Hardness modulus was best correlated with density of the hardness specimen (R = 0.87). Correlations with specimen ultrasonic E or with twelfth-panel density were only moderately good (R = 0.6) and with full-panel density insignificant. Correlations with ultrasonic τ or with any of the full-panel properties were poor to insignificant.

Evaluation of Plate Shear Properties

Correlation coefficients between plate shear and NDT properties are given in table 16. In general, better correlations were obtained for plate shear modulus than for plate shear stiffness, perhaps because plate shear modulus corrects for thickness. Shear modulus was best correlated with density or ultrasonic E of the plate shear specimen (R = 0.8). It was also well correlated with twelfth-panel density or ultrasonic E (R = 0.7) but poorly with full-panel ultrasonic E (R = 0.44). Correlation coefficients with full-panel sag E were insignificant.

Table 9.—Summary of correlations between static bending and nondestructive properties[1,2]

Specimen type	Property[1]	Correlation coefficient: Along panel, Maximum load	Along panel, Modulus of rupture[3]	Across panel, Maximum load	Across panel, Modulus of rupture[3]
		UNTREATED BENDING SPECIMENS			
Static bending	Density	0.54	0.32	0.42	0.48
	Ultrasonic t	-.56	-.61	-.35	-.41
	Ultrasonic E	.67	.75	.52	.60
	Static E	.71	.82	.62	.72
Twelfth panel	Density	.45	.48	.41	.48
	Ultrasonic t	-.45	-.44	-.56	-.54
	Ultrasonic E	.53	.54	.64	.67
Full panel	Density	.10	.14	.15	.07
	Ultrasonic t	-.23	-.28	-.42	-.49
	Ultrasonic E	.25	.30	.39	.46
	Sag E	.22	.20	.06	.08
		WET-TREATED BENDING SPECIMENS			
Static bending	Ultrasonic E	0.67	0.69	0.77	0.80
	Static E	.69	.79	.79	.89
Twelfth panel	Ultrasonic E	.64	.69	.68	.70
Full panel	Ultrasonic E	.20	.29	.39	.48
	Sag E	.12	.15	.10	.12
		AGE-TREATED BENDING SPECIMENS			
Static bending	Ultrasonic E	0.64	0.75	0.59	0.68
	Static E	.80	.87	.78	.84
Twelfth panel	Ultrasonic E	.45	.55	.58	.62
Full panel	Ultrasonic E	.17	.28	.33	.44
	Sag E	.03	.03	.10	.11

[1]Maximum load and modulus of rupture compared to the listed properties.

[2]Each number based on 65 paired values.

[3]Based on dimensions before any treatment.

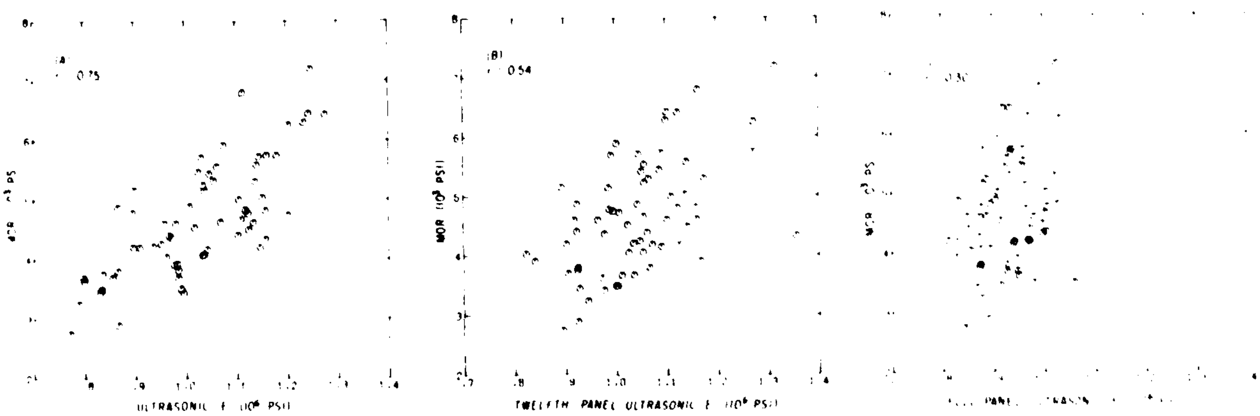

Figure 6.—Correlations of modulus of rupture for untreated static-bending specimens with ultrasonic E—along-panel direction. E is taken from (A) static-bending specimen, (B) twelfth-panel specimen, and (C) full-panel specimen.

The negative correlation coefficient between shear stiffness and full-panel density (R = −0.30), while statistically significant (5 pct level), makes little sense as it suggests that shear stiffness decreases as panel density increases.

Summary and Conclusions

One hundred and fifty-one full-size structural flakeboard panels constructed from forest logging residue and specimens cut from some of these panels were subjected to nondestructive tests including ultrasonics and static bending.

Ultrasonic modulus of elasticity was greater in the along-panel direction than in the across-panel direction—by about 22 percent in the full panel. Ultrasonic E tended to increase as the ultrasonic timing distance decreased, and varied both within and between panels. The along-panel and across-panel ultrasonic E's determined on the larger pieces were only moderately well correlated, suggesting that the along-panel ultrasonic E would not be very useful for predicting across-panel properties. Correlations of ultrasonic E's were generally poor between small specimens and full panels.

Ultrasonic stress-wave time (time per unit transit distance) was correlated to the same variables as E. Sensitivity to panel size, test orientation, and destructive properties was very similar to that found with ultrasonic E.

Static bending E's of unaged bending specimens averaged about 73 percent of the ultrasonic E's of those specimens. Correlations of static E's of the bending specimens with ultrasonic E's were best for the static-bending specimen and least for the full panels.

Thickness and density were found to be variable, both within and between panels, even though all panels were to be made alike. These variations undoubtedly had an effect on the stress-wave properties, as well as on the destructive properties.

Table 10.—Summary of correlations between internal bond and nondestructive properties[1]

Specimen type	Property	Correlation coefficient: Along panel	Correlation coefficient: Across panel
Static bending	Density	0.40	
	Ultrasonic τ	−.42	
	Ultrasonic E	.51	−0.02
Twelfth panel	Density	.21	
	Ultrasonic τ	−.32	
	Ultrasonic E	.29	−.06
Full panel	Density	.16	
	Ultrasonic τ	−.29	
	Ultrasonic E	.33	−.25
	Sag E	.16	.35

[1]Each number based on 65 paired values

Table 11.—Summary of correlations between interlaminar shear and nondestructive properties[1]

Specimen type	Property	Correlation coefficient: Shear stiffness	Shear modulus	Maximum shear load	Maximum shear stress
Interlaminar shear	Density	0.74	0.75	0.63	0.63
	Ultrasonic τ	−.38	−.34	−.33	−.33
	Ultrasonic E	.69	.66	.59	.59
	Shear modulus			.83	.81
Twelfth panel	Density	.72	.72	.60	.59
	Ultrasonic τ	−.51	−.52	−.45	−.44
	Ultrasonic E	.74	.72	.63	.62
Full panel	Density	.17		.20	
	Ultrasonic τ	−.44		−.41	
	Ultrasonic E	.41	.44	.48	.46
	Sag E	.23	.23	.30	.30

[1]Each number based on 65 paired values.

Table 12.—Summary of correlations between rail shear and nondestructive properties[1]

Specimen type	Property	Correlations coefficient: Maximum shear load	Maximum shear stress
Rail shear specimen	Density	0.56	0.60
	Ultrasonic τ	−.46	−.43
	Ultrasonic E	.59	.62
Twelfth panel	Density	.44	.48
	Ultrasonic τ	−.45	−.46
	Ultrasonic E	.53	.56
Full panel	Density	.18	
	Ultrasonic τ	−.42	
	Ultrasonic E	.45	.49
	Sag E	.19	.19

[1]Each number based on 65 paired values.

Table 13.—Summary of correlations between nail and nondestructive properties

Specimen type	Property[1]	Correlation coefficient: Along panel: Lateral resistance	Along panel: Withdrawal resistance	Along panel: Head pull through	Across panel: Lateral resistance	Across panel: Withdrawal resistance	Across panel: Head pull through
		UNTREATED NAIL SPECIMENS[2]					
Static bending	Density	0.57			0.40		
	Ultrasonic τ	−.11			−.12		
	Ultrasonic E	.42	0.28	0.64	.31	0.29	0.41
Twelfth panel	Density	.55			.29		
	Ultrasonic τ	−.32			.06		
	Ultrasonic E	.52	.32	.64	.11	.34	.46
Full panel	Density	.16			−.13		
	Ultrasonic τ	−.19			[3] −.01		
	Ultrasonic E	.23	.33	.32	[3] .00	[3] .23	[3] .30
	Sag E	.12	.07	.28	.00	.13	.10
		WET-TREATED NAIL SPECIMENS[4]					
Nail specimen	Density	0.62	0.69	0.60	0.47	0.70	0.69
	Ultrasonic τ	−.13	−.19	−.14	−.09	−.03	.20
	Ultrasonic E	.44	.45	.53	.36	.43	.22
Twelfth panel	Density	.63	.52	.58	.50	.70	.63
	Ultrasonic τ	−.47	−.40	−.32	−.38	−.28	−.16
	Ultrasonic E	.63	.52	.52	.50	.51	.39
Full panel	Ultrasonic E	.39	.26	.21	[3] .38	[3] .32	[3] .32
	Sag E	−.04	.04	.00	.01	.14	−.03
		AGE-TREATED NAIL SPECIMENS[4]					
Nail specimen	Density	0.49		0.45	0.44		0.37
	Ultrasonic τ	−.15		−.28	−.41		−.11
	Ultrasonic E	.43		.50	.57		.28
Twelfth panel	Density	.29		.48	.54		.42
	Ultrasonic τ	−.21		−.39	−.38		−.20
	Ultrasonic E	.29		.50	.52		.32
Full panel	Ultrasonic E	.23		.42	[3] .36		[3] .35
	Sag E	.08		.12	.18		−.05

[1]Based on dimensions before any treatment.

[2]Each number based on 62 paired values.

[3]Correlations with along-panel unit ultrasonic time and ultrasonic E.

[4]Each number based on 65 paired values.

Corrected for panel thickness, stiffness of the quarter panels under concentrated load correlated moderately well with ultrasonic E of the same quarter panels but only poorly with ultrasonic E of the full panels. Shear modulus for either plate shear or interlaminar shear also correlated moderately well with ultrasonic E of the panels on which the measurements were made but only poorly with ultrasonic E of the full panels.

As a very general observation, correlations of the various destructive properties (e.g., modulus of rupture, internal bond, shear strength, etc.) tended to be moderately good at best with ultrasonic E of the destructive specimens themselves; the correlations were worse with ultrasonic E of the larger specimens from which they were cut. Correlations tended to be less good with unit ultrasonic time than with ultrasonic E. Correlations with density also tended to be only moderately good at best, except for a few selected properties such as hardness modulus which is a semidestructive test.

Recommendations for Future Study

While the results of this study suggest that destructive properties of this research-type flakeboard

Table 14.—Summary of correlations between ball impact and nondestructive properties[1,2]

Specimen type	Property	Correlation coefficient			
		First crack		Failure	
		Unadjusted	Adjusted	Unadjusted	Adjusted
Ball impact	Density	0.09	0.17	0.36	0.44
	Ultrasonic τ	−.13	.16	−.50	−.53
	Ultrasonic E	.14	.19	.51	.57
	Failure, unadjusted	.47			
Twelfth panel	Density			.30	.37
	Ultrasonic τ	−.16	−.20	.59	−.62
	Ultrasonic E	.13	.24	.50	.59
Full panel	Density			−.24	−.16
	Ultrasonic τ			−.45	−.53
	Ultrasonic E	.02	.13	.34	.47
	Sag E	.00	.03	−.06	−.05

[1]Each number based on 63 paired values for first crack, 64 for failure.

[2]Unadjusted implies not corrected for thickness; adjusted implies dividing drop height by specimen thickness.

Table 15.—Summary of correlation coefficients between hardness modulus and nondestructive properties[1]

Specimen type	Property	Correlation coefficient
Hardness	Density	0.6[illegible]
	Ultrasonic τ	−.16
	Ultrasonic E	.59
Twelfth panel	Density	.56
	Ultrasonic τ	−.26
	Ultrasonic E	.47
Full panel	Density	.08
	Ultrasonic τ	−.24
	Ultrasonic E	.2[illegible]
	Sag E	.3[illegible]

[1]Each number based on 65 paired values.

Table 16.—Summary of correlation coefficients between plate shear and nondestructive properties[1]

Specimen type	Property	Correlation coefficient	
		Shear stiffness	Shear modulus
Plate shear	Density	0.52	0.82
	Ultrasonic τ	−.28	−.41
	Ultrasonic E	.51	.78
	Shear modulus	.64	
Twelfth panel	Density	.38	.71
	Ultrasonic τ	−.20	−.56
	Ultrasonic E	.32	.73
Full panel	Density	−.30	
	Ultrasonic τ	−.09	
	Ultrasonic E	−.02	.44
	Sag E	−.10	.06

[1]Each number based on 65 paired values.

generally relate only moderately well to nondestructive properties, the results are based on a quite limited scope in panel formulations and specimen sizes. Therefore, this study suggests two items of major concern for further nondestructive testing research on panel products.

1. Where predictive models are a goal, experimental panels should be made with an extended range of quality by varying resin content, press temperature, etc., to simulate the kinds of panels that may be produced when manufacturing variables run beyond control limits. The extended quality should allow for better modeling between destructive and nondestructive tests than was possible in this study.

2. To be of practical use to the manufacturer and user of flakeboard, future nondestructive evaluations should be based on destructive tests of full panels or large pieces consistent with end-use sizes rather than on small specimens cut from a panel.

Literature Cited

1. American Society for Testing and Materials. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Design. D 1037-72a: 1972.

2. American Society for Testing and Materials. Standard methods of test for shear modulus of plywood. ASTM Design. D 3044-72: 1972.

3. Burmeister. A. [On the correlation between sound velocity and density, tensile strength perpendicular to the surface and bending strength of particleboard.] Holz als Roh-und Werkstoff 26(4):113- 117: 1968.

4. Gerhards. C. C. Comparison of two nondestructive instruments for measuring pulse transit time in wood. Wood Sci. 11(1):13- 16: 1978.

5. McNatt. J. D. Manufacture and performance of full-size structural flakeboards from Douglas-fir forest residues. Proc. Symp. Structural Flakeboards from Forest Residues. Kansas City, Mo. USDA For. Serv. Gen. Tech. Rep. WO- 5. p. 118-132: 1978.

6. Pellerin. R. F.: Morschauser. C. R. Nondestructive testing of particleboard. Proc. 7th Washington State Univ. Symp. on Particleboard. Pullman; p. 251-260. 1973.

7. Superfesky. M. J.; Montrey. H. M.; Ramaker. T. J. Floor and roof sheathing subjected to static loads. Wood Sci. 10(1):31-41. 1977.

Appendix

The appendix contains data pertinent to simple linear regressions of the form Y = A + BX. These data are based on regressions with correlation coefficients of 0.5 and greater. Caution is advised in the use of these data, however, as they are based on a particular type of experimental flakeboard. The results should not be applied directly to other particleboard or flakeboard products as they may yield false or unsafe predictions of mechanical properties.

Table 17.—NDT regressions based on data for 151 [illegible] (Y = A + BX)

Variables: Y	Variables: X	Coefficients: A	Coefficients: B	Standard error of Y	Standard deviation of Y
Ultrasonic τ across panel, μs/in.	Ultrasonic τ along panel, μs/in.	2.18	0.5[illegible]	0.34	0.40
Ultrasonic E across panel, 10^6 lb/in.²	Ultrasonic E along panel, 10^6 lb/in.²	[illegible]	.656	.055	.063
Sag E, 10^6 lb/in.²	Ultrasonic E along panel, 10^6 lb/in.²	.36	.569	.067	.073

Table 18.—NDT regressions, each number based on 65 paired values (Y = A + BX)

Specimen or correlated variable	Specimen or variable: Y	Specimen or variable: X	Coefficients: A	Coefficients: B	Standard error of Y	Standard deviation of Y
Ultrasonic τ along panel, μs/in.	Plate shear	1/12 panel	2.86	0.626	0.14	0.23
	Plate shear	1/4 panel	3.78	.512	.18	.23
	Bending	1/12 panel	2.80	.947	.25	.41
	Bending	1/4 panel	2.83	.646	.25	.31
	Rail shear	1/12 panel	1.31	.802	.21	.30
	Rail shear	1/4 panel	1.40	.782	.22	.30
Ultrasonic τ across panel,	Bending	1/12 panel	2.14	1.038	.34	.43
	Bending	1/4 panel	2.13	.689	.32	.43
Ultrasonic E along panel, 10^6 lb/in.²	Plate shear	1/12 panel	.30	.754	.048	.097
	Plate shear	1/4 panel	.31	.746	.072	.097
	Bending	1/12 panel	.18	.812	.091	.126
	Bending	1/4 panel	.22	.797	.105	.126
	Rail shear	1/12 panel	−.01	1.142	.078	.146
	Rail shear	1/4 panel	−.03	1.160	.104	.146
Ultrasonic E across panel, 10^6 lb/in.²	Bending	1/12 panel	.20	.786	.077	.107
	Bending	1/4 panel	.19	.970	.077	.107
Bending along panel, 10^6 lb/in.²[1]	Static E	Ultrasonic E	−.06	.775	.07	.12
[1]Bending across panel, 10^6 lb/in.²	Static E	Ultrasonic E	−.03	.789	.08	.11

[1]Unaged specimens.

Table 19.—Regressions of selected destructive and NDT properties[1]

Variables: Y	Variables: X	Coefficients: A	Coefficients: B	Standard error of Y	Standard deviation of Y
Concentrated puncture load/thickness, lb/in[2]	1/4-panel ultrasonic E along panel, 10^6 lb/in²	60	1,440	154	198
Bending MOR along panel, lb/in²	Specimen ultrasonic t along panel, µs/in	19,890	1,[illegible]	[illegible]	[illegible]
	Specimen ultrasonic E along panel, 10^6 lb/in²	1,[illegible]	5,630	636	[illegible]
	Specimen static E, 10^6 lb/in²	[illegible]	6,340	556	[illegible]
	1/12-panel ultrasonic t along panel, µs/in	[illegible]	[illegible]	[illegible]	[illegible]
	1/12-panel ultrasonic E along panel, 10^6 lb/in²	280	4,74[illegible]	[illegible]	[illegible]
	Full-panel ultrasonic t along panel, µs/in	13,690	1,052	921	[illegible]
	Full-panel ultrasonic E along panel, µs/in	70	5,090	914	[illegible]
Bending MOR across panel, lb/in²	Specimen ultrasonic t across panel, µs/in	11,310	803	768	836
	Specimen ultrasonic E along panel, 10^6 lb/in²	50	4,720	674	836
	Specimen static E, 10^6 lb/in²	720	5,240	587	836
	1/12-panel ultrasonic t across panel, µs/in	15,440	1,274	709	836
	1/12-panel ultrasonic E across panel, 10^6 lb/in²	990	5,950	627	836
	Full-panel ultrasonic t across panel, µs/in	13,660	980	734	836
	Full-panel ultrasonic E across panel, 10^6 lb/in²	150	5,920	740	836
Interlaminar shear modulus, modulus, lb/in²	Specimen ultrasonic E along panel, 10^6 lb/in²	6,300	31,400	5,550	[illegible],430
	1/12-panel ultrasonic E along panel, 10^6 lb/in²	8,900	50,300	5,080	[illegible],430
Interlaminar maximum shear stress, lb/in²	Specimen ultrasonic E along panel, 10^6 lb/in²	[illegible]0	275	59	73
	1/12-panel ultrasonic E along panel, 10^6 lb/in²	36	413	58	[illegible]
Rail maximum shear stress, lb/in²	Specimen ultrasonic E along panel, 10^6 lb/in²	410	1,070	198	[illegible]
	1/12-panel ultrasonic E along panel, 10^6 lb/in²	[illegible]70	1,310	209	[illegible]
Plate shear modulus, 10^3 lb/in²	Specimen ultrasonic E along panel, 10^6 lb/in²	[illegible]	242	[illegible]	30
	1/12-panel ultrasonic E along panel, 10^6 lb/in²	90	195	[illegible]	30

[1]Each number based on 65 paired values (Y = A + BX).

[2]Concentrated puncture load/thickness based on only 56 paired values.

U.S. Forest Products Laboratory

Nondestructive evaluation of mechanical properties of a structural flakeboard made from forest residues, by C. C. Gerhards and L. H. Floeter, Madison, Wis., For. Prod. Lab., 1982

17 p. (USDA For. Serv. Res. Pap. FPL 414).

Full-sized flakeboard panels made of logging residues, and small specimens cut from those panels, were subjected to several nondestructive tests including ultrasonic and impact stress-waves. Small specimens were tested to destruction to determine strength properties.

Some nondestructive properties correlated highly with each other, particularly within specimens. Correlations between destructive and nondestructive properties were only moderately good.

Keywords: Nondestructive testing, mechanical properties, ultrasonics, stress-wave, structural flakeboard, sag bending, forest residues.

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